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CRANK CASE SCAVENGING OF A TWO-STROKE-CYCLE ENGINE

By Otto Holm

From "Zeitschrift des Vereines deutscher Ingenieure"  
June 11, 1927

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CRANK CASE SCAVENGING OF A TWO-STROKE-CYCLE ENGINE.\*

By Otto Holm.

Experiments with a two-stroke-cycle, crank case scavenging engine. Effect of systematic variation of the height of the scavenge and exhaust ports on the scavenging, as determined by gas analysis. The best results were obtained under conditions differing from the usual ones.

The crank case scavenge pump commonly used in small two-stroke-cycle engines is generally reputed to have a very low volumetric efficiency. This is due to the large dead spaces in the crank case which, at best, amount to four or five times the stroke volume and depend somewhat on the make. Figures are hardly to be found for the efficiency of scavenge pumps on the basis of experiments. Uncertainty regarding the efficiency of the scavenge pumps is shown in the dimensions of the scavenge and exhaust ports, which still differ greatly.

I have therefore thoroughly investigated the effect of the dimensions of the scavenge and exhaust ports on the efficiency

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\*"Die Kurbelkastenspülung eines Zweitaktmotors," from "Zeitschrift des Vereines deutscher Ingenieure," June 11, 1927, pp. 847-850. This is an abstract, by the author, from a dissertation accepted by the Danzig Technical High School. The full text appeared in "Autotechnik," Vol. 16 (1927), No. 7.

of the scavenging. For this purpose, I used a 15 HP. hot-bulb engine. The functioning method of the experimental engine is, however, comparatively unimportant in judging the results. These would have hardly been affected had the experiments been performed on a compressorless two-stroke Diesel engine, as was indicated by several control experiments on the latter.

In addition to the customary temperature measurements, which are indispensable for maintaining uniform temperatures during the experiments (inflow and outflow of cooling water, scavenge air, exhaust, hot bulb), measurements had to be made of the quantities from which the composition and possibly also the weight of the gas charge in the cylinder immediately before the beginning and after the completion of the scavenging could be computed. For this purpose holes were drilled in the cylinder and in the exhaust pipe, and mechanically controlled valves were installed for taking gas samples (Fig. 1).

The operation of the valves is shown in Fig. 2. Through the lateral displacement of the roller lever, either one of five neighboring cams on the engine shaft can be brought into action by a simple manipulation, so that during the same experiment, gas samples can be taken at five different points of the working cycle. The length of time consumed in taking a sample corresponded to a crank angle of about 6 degrees. In addition to the mechanically operated valves, a tube was also installed for taking gas samples from the exhaust pipe without mechanical control.

The quantity of air inducted was measured by a vane wheel (Figs. 3-4). For damping the pressure oscillations in the intake pipe, an intake chamber of 2 m<sup>3</sup> (70 cu.ft.) was installed. In order to be able to regain the same thermal condition of the engine on different days with the least possible loss of time, the quantity of cooling water could be directly and accurately read with the aid of a Pitot tube. The horsepower was determined by means of a water brake and a revolution counter. The fuel meter (Fig. 5), with 8 needles suspended in the measuring glasses, when used with a stop watch, enables very accurate continuous measurements without interfering with the other observations. Exactly equal vertical distances separate the ends of the needles, which are successively left by the receding liquid.

It would have been natural to measure the air quantities with a standard nozzle or a restricted opening into the intake chamber. A U-tube manometer was added to the intake chamber to measure the negative pressure. In order, however, to make fairly accurate measurements with Pitot tubes, it would have been necessary to have a negative pressure of about 200 mm (7.87 in.) water column in the intake chamber. This was very undesirable and would have reacted on the inducted quantities of air and consequently on the engine power and the other working characteristics. The intake valves of the scavenge pump require negative pressures of only 0.02-0.04 atmosphere (0.28-0.57 lb./sq.in.) - 200-400 mm

(7.87-15.75 in.) water column during the suction stroke. Since even slight differences in the resistance of the intake valve had been found to have considerable effect on the engine power, it was necessary to use a meter with the least possible resistance.

Therefore a vane wheel was used (Fig. 3). The calibration curve of this wheel, as found in a uniform air flow (Fig. 6) shows that the wheel, which is mounted on jewel bearings and transmits its motion to a recording mechanism, is practically frictionless, its resistance at full engine speed corresponding to only 1-2 mm (0.04-0.08 in.) water column.

In spite of the intake chamber, it was not possible entirely to prevent pressure and velocity variations of the air flowing through the instrument. The experiments showed that the wheel, with the same volume of air per unit of time, revolved faster in a pulsating air flow than in a uniform one. The resulting error could be determined only by damping the air oscillations in the instrument, so that its readings in a uniform air current could be compared with the readings in a pulsating current.

For this purpose, perforated metal sheets were inserted as dampers between the vane wheel and the intake chamber. These sheets damped the oscillations of the air without greatly reducing the air flow, as was determined by special calibration tests. Above a certain negative pressure in the intake chamber, the indications of the vane wheel agreed with those of the restricted op-

enings, for which Müller determined the flow coefficient.\*

Above this pressure, therefore, the fluctuations in the air velocity were so small that they hardly affected the indications of the vane wheel.

If, at a given engine speed, the results of the experiments with different damping sheets, having 113 holes uniformly distributed over the whole surface and differing only in the size and not in the location of the holes, are plotted (Fig. 7), the error of the vane wheel without the damping sheet can then be determined from the following consideration. Above the negative pressure, at which the effect of the oscillations on the results practically disappears, the line shows only the decrease in the volumetric efficiency of the scavenge pump for further increases in pressure. Hence, if we extrapolate on this line, beyond the point of origin toward the left, an abscissa value, which corresponds to the condition without the damping sheet, then the corresponding ordinate closely approximates the quantity of air drawn in. The ratio of this quantity to that computed, on the basis of the calibration line, from the reading for the unequal air flow, is the correction factor by which the readings must be multiplied. It is less than unity, depends on the revolution speed, and asymptotically approaches unity at infinite speed.

Fig. 7 shows the determination of the correction factor for the engine speed of 453 R.P.M. It is  $\frac{RQ}{RP} = 0.945$ . The point P'

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\*A. O. Müller, "Messungen von Gasmengen mit der Drosselscheibe," "Forschungsarbeiten," No. 48.

was found in a control experiment. The points marked x were calculated from readings taken with restricted openings. They are more scattered than the results obtained with the vane wheel. The correction factors for the vane wheel were thus determined for 5 revolution speeds (Fig. 8). As shown by very many careful measurements, errors up to 3% must be expected in measuring the quantity of air.

From the analysis of the gas samples taken just before and just after the scavenging, the efficiency of the latter, i.e., the percentage of pure scavenge air in the charge, can be calculated. This requires, however, that the combustion water, on the basis of the fuel analysis (for gas oil: C, 86.82%; H, 13.18%), be taken into account. The calculation of the requisite quantity of scavenge air and of the efficiency of the scavenging is made from the fuel consumption and from the inducted air, as the only measured quantities.

It is noteworthy that in the crude-oil engine, even with overloading and a very smoky exhaust, not any, or hardly any, carbon monoxide is formed. The fuel apparently disintegrates, with lack of air, and largely leaves the exhaust pipe unburned, with the liberation of carbon in the form of soot. Unfortunately this renders it impossible to calculate accurately the requisite quantity of scavenge air, since the quantity of lost fuel vapor cannot be determined by analysis nor in any other way. The results must therefore be regarded only as maximum values. In

smokeless combustion, these values are approximated or equaled by the true values, the latter being smaller, however, in smoky combustion. On the other hand, it can be demonstrated that the computed efficiency of the scavenging process even then practically agrees with the actual efficiency, when considerable quantities of the unburned constituents are not included in the analysis.

The taking of the samples requires great care and months of practice. By taking samples from the exhaust pipe, it was found that the samples taken from near the cylinder walls corresponded accurately enough to the mean composition of the combustion gases in the center of the charge.

The first group of experiments was intended to show, among the quantities standing in unavoidable reciprocal relations, only the effect of the height of the scavenge ports; the second, only the effect of the height of the exhaust ports on the scavenging process. The third and fourth groups of experiments furnished information on the effect of several changes in the shape of the openings of the scavenge channels and of the piston. The scavenge and exhaust channels were modified by fitting in pieces, as shown in Figs. 9-18.

Group I.								
Experiment No.	1	2	3	4	5	6	7	8
Piece	AF	AG	BF	BG	AF	BF	CG	CF
Series	2	2	2	2	1	1	2	2



Group II.								
Experiment No.	1	5	9	2	10	11	12	13
Piece	AF	AF	AG	AG	AH	AH	AJ	AJ
Series	2	1	1	2	2	1	1	2

Group III.			
Experiment No.	14	15	16
Piece	DF	DF	DG
Series	1	2	2

Group IV.	
17	18
EF	EJ
1	2

All experiments were performed in two series, at about 450 and 290 R.P.M., the results being shown graphically in Figs. 19-22. The so-called "time cross sections" of the early exhaust and of the scavenging were chosen as the mutual reference quantities. The time cross section of the scavenging is the integral of the product of the free scavenge cross section and the time from the opening to the closing of the scavenge ports by the piston. The time cross section of the early exhaust is correspondingly the integral of the product of the cross section of the exhaust ports and the time from the opening of these ports to the uncovering of the scavenge ports by the piston. The charge efficiency is the ratio of the gas volume at 15°C and 760 mm Hg, as calculated from gas analyses and fuel consumption, to the cylinder contents at the closing of the exhaust ports.

The first group of experiments gave, at a sufficiently large time cross section of the scavenging, volumetric efficiencies of

the scavenge pump which were greater than unity. In the second group of experiments, the engine still worked very well with equally high scavenge and exhaust ports.

In most of the experiments a small exhaust muffler of 32 liters (1953 cu.in.) capacity was installed in the exhaust pipe close to the working cylinder. Since the high efficiency of the scavenge pump might be due to the oscillations of the gas columns in the exhaust pipe, check tests were made with an exhaust muffler of 470 liters (28,681 cu.in.) capacity. The efficiency of the scavenge pump was thereby diminished but remained constant, while with the small muffler it varied with the revolution speed, according to the resonance effect of the oscillating exhaust columns.

In Fig. 22 the higher points of the lines III and V at 450 R.P.M. correspond to the lower points of the experiments at 290 R.P.M. Moreover, the results with the large muffler were somewhat less favorable in the tested range of revolution speeds. Hence, with two-stroke engines, the best results are not always obtained by the free exit of the exhaust gases. The fact that a smaller early exhaust is favorable may be explained by the fact that increasing the power stroke has a beneficial effect at a smaller height of the exhaust ports. The effect of increasing the power stroke on the specific fuel consumption is shown in Fig. 21 by the values of line III, which were obtained by converting the experimental values to the same effective stroke vol-

ume. Thereby the procedure is from the admissible assumption that the fuel consumption is inversely proportional to the stroke volume. At a small height of the exhaust ports, the somewhat higher compression and the smaller fluctuations in the pressure difference between the cylinder and scavenge pump during the scavenging process (hence eddy-free flow and a better scavenge picture) might, moreover, be of advantage, whereas the initial penetration of the exhaust gases into the crank case probably does not matter so much.

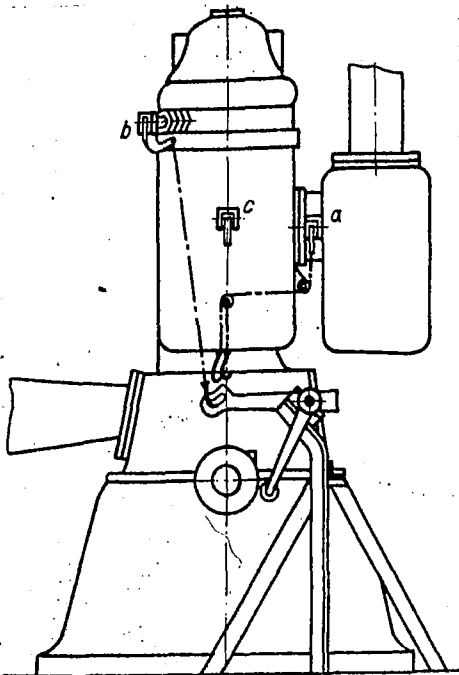
The results of the experiments have been confirmed on various other engines. Among others it was found possible, with a relatively great height of the scavenge ports and small height of the exhaust ports, to obtain, on a 25 HP. two-stroke Diesel engine with crank case scavenge pump (ignition-chamber method) 210 mm (8.27 in.) bore, 340 mm (13.39 in.) stroke and 400 R.P.M.) and perfect combustion, a continuous production of 31.4 HP<sub>e</sub>, which corresponds to a mean effective piston pressure of 3 atmospheres (42.67 lb./sq.in.).

The shape D (Fig. 13) of the scavenge ports gave a poor scavenge efficiency, since the scavenge air in any event escapes over the piston head through the exhaust ports.

The inertia effect of the exhaust columns may, with a not-too-large muffler and connecting pipe, have the result that scavenge air is drawn beyond the stroke of the scavenge pump and that a very high volumetric efficiency of the scavenge pump is attained.

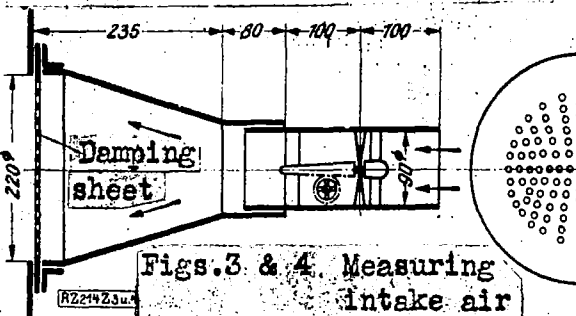
Progress is still possible in this direction, though new methods must be employed. It is important not to dissipate the kinetic energy of the gases in large mufflers, but to utilize it, whereby the matter of resonance would only constitute one part of the problem. This is possible only in pipes without any, or only slight, sudden increases in cross section (mufflers). The regions of resonance are, moreover, not so sharply confined that they cannot be technically utilized.

Translation by Dwight M. Miner,  
National Advisory Committee  
for Aeronautics.



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Fig. 2 Operation of sample-taking valves.



Figs. 3 & 4 Measuring intake air

- a, Valve on exhaust pipe.
- b, Upper valve
- c, Lower valve

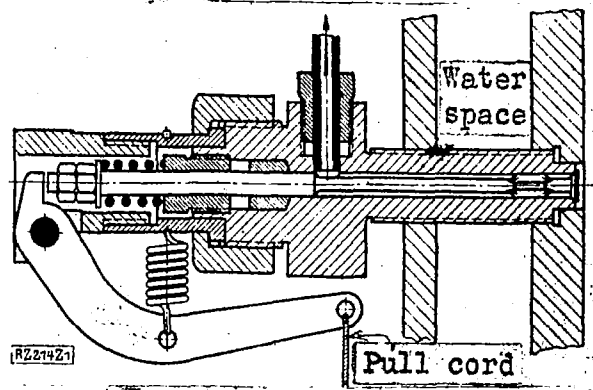


Fig. 1 Valve for taking gas samples

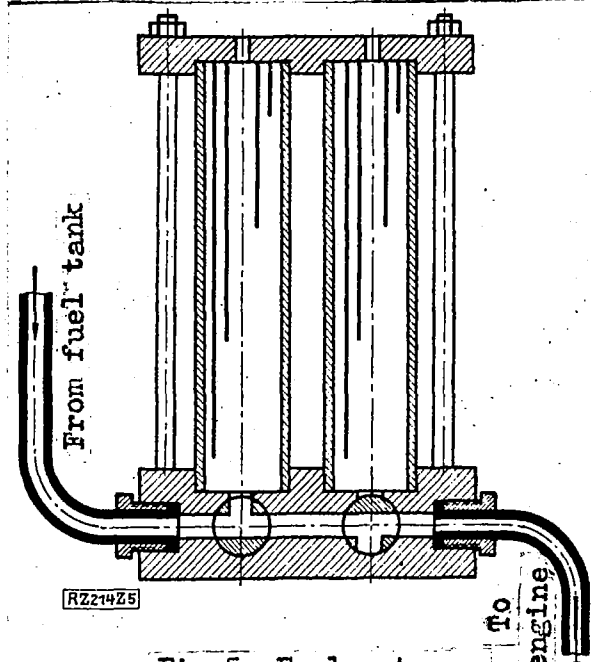
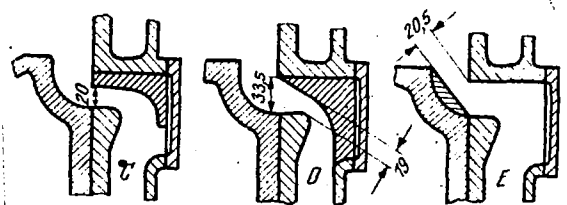
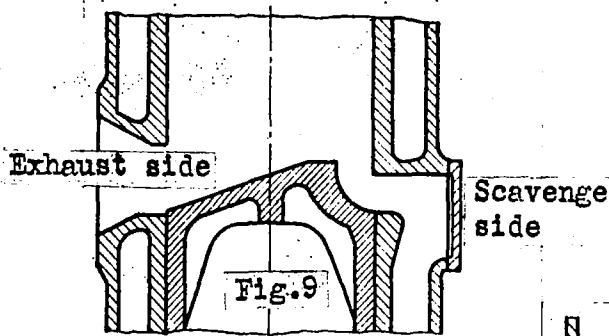
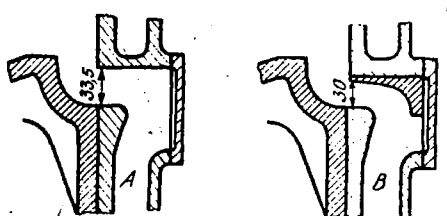


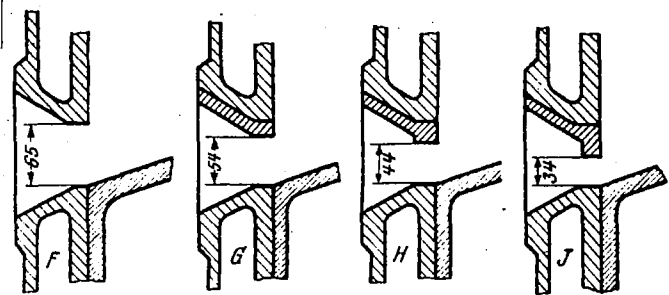
Fig. 5 Fuel meter



Figs. 12, 13 & 14 Scavenge side



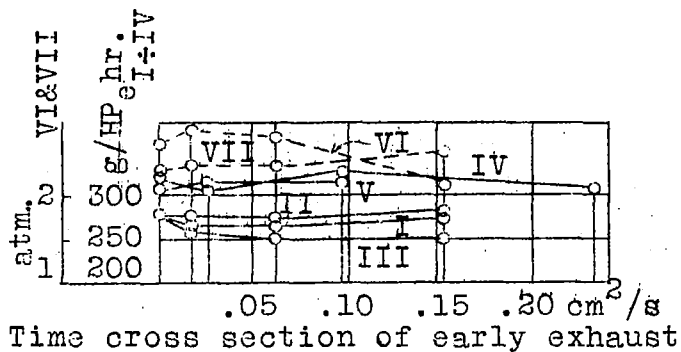
Figs. 10 & 11 Scavenge side



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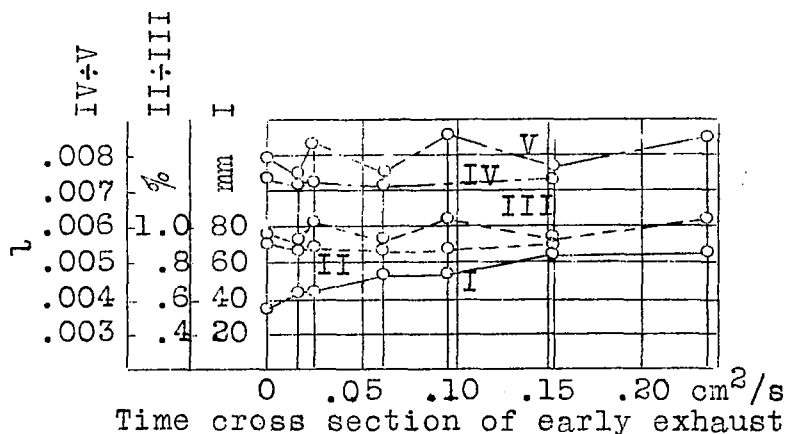
Figs. 15 to 18 Exhaust side

Figs. 9 to 18 Modification of ports by fitted pieces



- I Spec. fuel consumption series 1 with small muffler.  
 II " " " " " " " " large " "  
 III Reduced spec. fuel consumption.  
 IV Spec. fuel consumption series 2 with small muffler.  
 V " " " " " " " " large " "  
 VI Max. mean effective press. series 1 with small muffler.  
 VII " " " " " " " " large " "

Fig.21 Experimental results.



- I Height of exhaust port.  
 II Vol. efficiency of scavange pump with large muffler.  
 III " " " " " " " " small " "  
 V Amt. of air removed by one revolution with small muffler.  
 IV " " " " " " " " large " "

Fig.22 Experimental results.

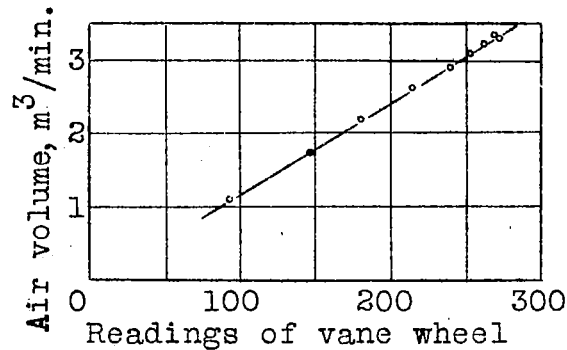


Fig. 6 Calibration lines of vane wheel.

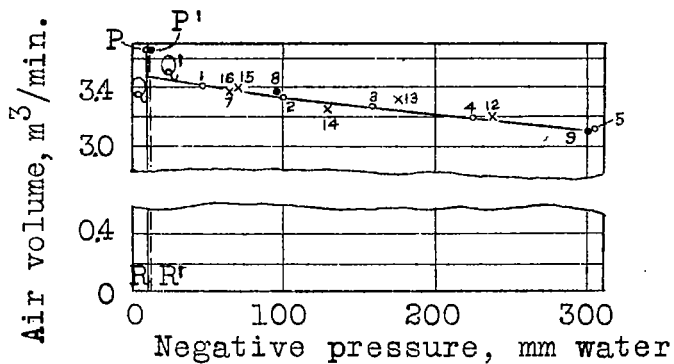


Fig. 7 Air volumes with various damping sheets and restricted openings at 453 R.P.M.

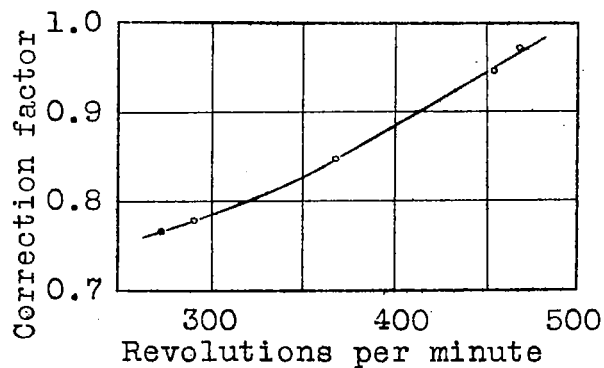
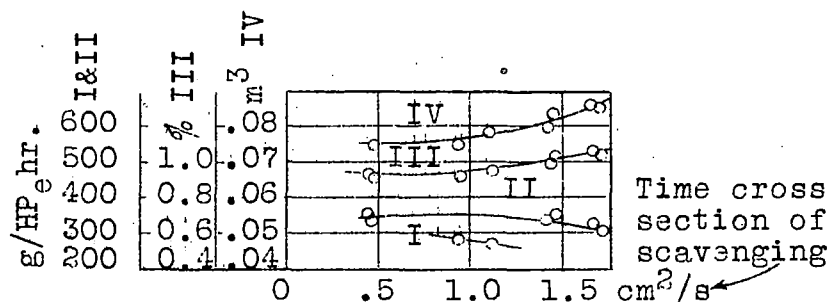
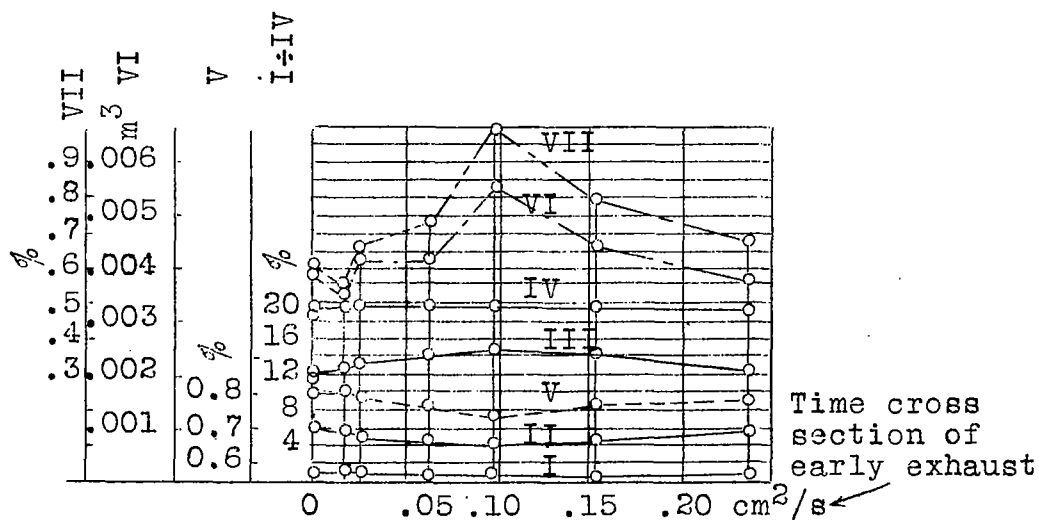


Fig. 8 Correction factors for various revolution speeds.



- I Spec. fuel consumption of 1st. series of experiments.  
 II " " " 2nd. " " "  
 III Vol. eff. of crankcase scavenging.  
 IV Vol. of air drawn in during one revolution.

Fig.19 Experimental results.



- I  $\text{CO}_2$  at beginning of compression.  
 II " " end of expansion.  
 III Oxygen at end of expansion.  
 IV " " beginning of compression.  
 V Scavenge efficiency.  
 VI Effective vol. of scavenge air.  
 VII Charge efficiency.

Fig.20 Experimental results.



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